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research trends

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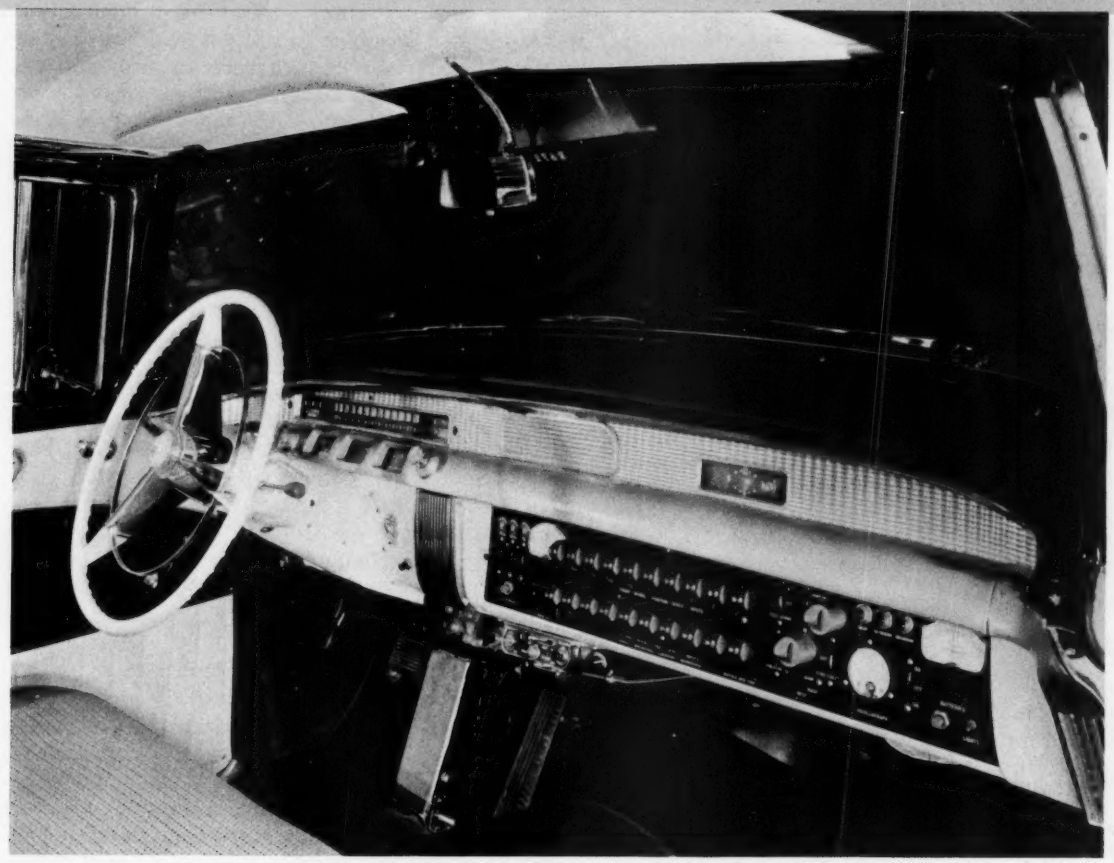


FIG. 1.

Control console of variable-stability automobile developed at CAL.

The Automobile and its Driver . . .

A Man-Machine System

by LEONARD SEGEL

AUTOMOTIVE research at Cornell Aeronautical Laboratory over the past eight years has been directed toward defining the dynamics of automobile stability and control. The aim of the program was not to improve the product, but to compile theoretical and actual data that can assist automotive engineers in designing a safer, more maneuverable car. Germane to such aims is the fact that automobiles are built to be controlled by human operators.

Consider for a moment what we do with our cars as we drive over a road network without colliding with other vehicles, pedestrians, or obstructions. Once the learning period is over, we feel perfectly confident in our ability to control the path of the car so that we do not hesitate to drive at 60 mph with our vehicle displaced laterally, perhaps two or three feet, from another car going at the same speed in the opposite direction.

Two million foot-pounds of kinetic energy are being controlled by two drivers in this encounter, yet little or no thought is given by either driver to the possible hazards in what appears to be a routine control task. In other words, we have continual evidence to show that the driver and his automobile represent a man-vehicle system wherein the control relationship between man and the machine produces a high level

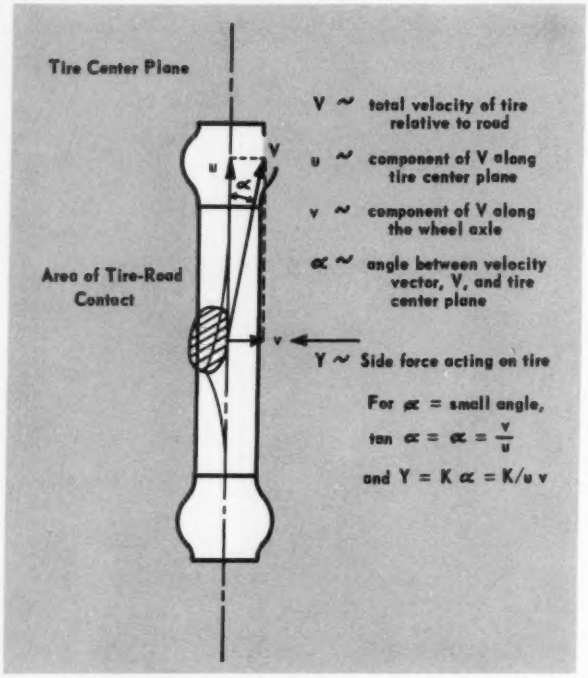

Tire Center Plane
V ~ total velocity of tire relative to road
u ~ component of V along tire center plane
v ~ component of V along the wheel axle
α ~ angle between velocity vector, V, and tire center plane
Area of Tire-Road Contact
Y ~ Side force acting on tire
For α = small angle,
tan α = α = v/u
and Y = K α = K/u v

FIG. 2 — **The lateral deformation caused by a side force acting on a rolling pneumatic tire.**

of control performance. On the other hand, the occurrence of near and actual collisions attests to the fallibility of the system.

Two Elements Involved

Research, much of it in the aeronautical field, has shown that the behavior of a man-vehicle system is a function of the dynamics of the two elements in the system — the controller (man) and the controlled element (machine). Specifically we have been concerned with the steering dynamics of the automobile, that is, the path response produced both by steering inputs and by such disturbing inputs as the wind or an irregular road.

Automotive research began in 1953 under sponsorship by the Research Laboratories of the General Motors Corporation. The original objectives, as stated in the CAL-GM research agreement, were:

"To undertake and conduct basic research and study in methods and techniques for the dynamic analysis of automobile directional stability and control, including but not limited to the following:

"1. The establishment of valid equations of vehicle motion.
"2. Comparisons of overall vehicle behavior with predictions based on these equations.
"3. A review of the dynamic theory and experimental data, a re-check of equations, and the establishment of firm analytical equations and constants."

It is worth noting that this type of automotive research is in distinct contrast with the more common investigations which are usually directed toward improving the various components of the automobile, such as engines, tires, brakes or body structure.

At the beginning of the CAL research effort, a literature search showed that efforts had indeed been made by others to describe the steering dynamics of the automobile. By and large, the equations of motion, previously derived for a four-wheeled, pneumatic-tired vehicle ignored (1) the roll degree of freedom of the automobile and (2) various other kinematic relationships resulting from the rolling motion produced by a turn. One point, however, stood out as more important than these seemingly unjustifiable simplifications. It was the lack of any experimental evidence to demonstrate whether the existing theories were adequate to predict the motion response (with time) as a function of a steering action. CAL, therefore, took as its first objective the experimental verification of equations of motion of an automobile moving in three degrees of freedom, namely turning or yawing, side motion or sideslipping, and rolling.

Stock Model Buick Instrumented

A 1953 Buick was instrumented to obtain dynamic recordings of the motions produced by steering displacements. The inactive runways of the Greater Buffalo International Airport provided the testing area. Meanwhile, a mathematical model was developed to describe the steering dynamics of the test car. Then vehicle-response data gathered with the car were compared with responses computed from the model. The experimental results substantiated the theory — a procedure which constituted the major difference between the approach adopted by CAL and what had been done previously by other investigators, either in this country or abroad.

A substantiated, mathematical model of the lateral stability and control of an automobile provided the analytical tool needed for the next step. While efforts were continued to expand and refine the theories relating vehicle-design parameters to the dynamic behavior of the controlled element, additional steps were taken to design and build an automobile to explore the behavior of the controller/controlled-element combination. Accordingly, a variable stability-and-control automobile was constructed analogous to the "rubber airplane" described in Research Trends, No. 2, Vol. 5, Summer 1957. Laboratory engineers instrumented a stock model Buick with two hydraulic servos to control the position of the front wheels and the torque on the steering wheel as a function of the motion of the car. Experience and background obtained in the design and construction of variable-stability aircraft assisted greatly in the development of the variable-stability automobile whose control console is depicted in Figure 1. This car is now being used by the General Motors Corporation in a long-range program of handling-qualities* research.

At this point in our discussion, it is desirable to point out some of the salient features of the steering (or lateral) dynamics of the wheeled vehicle. First, it should be recognized that the forces that guide or hold the vehicle in a curved path, (i.e., that provide the

*The term, "handling-qualities", is stability and control terminology for signifying those man-vehicle control relationships that have a bearing on control performance.

centripetal acceleration) derive from the pneumatic tire. Where the pneumatic tire touches the ground it is deformed laterally from the tire center plane when a side force is applied. For side forces less than three-tenths of the vertical load on the tire, the relationship between the side force and the lateral deformation is approximately linear. The lateral deformation is proportional to the ratio of the lateral velocity of the tire to the forward velocity. Accordingly, the side force is linearly related to the angle between the center plane and the total velocity vector of the tire. (Figure 2).

Origin of "Sure-footed" Feel

As a driver, you may have noticed that your car feels "sure-footed" at low and moderate speeds and "skittery" at high speeds. This feeling stems from what the industry has termed the "cornering stiffness" of the tire. Cornering stiffness is a function of the relationship between side force and slip angle. Its magnitude is the principal reason for your car's directional behavior.

For example, consider a constant side force acting on a car. It makes no difference whether this force comes from a cross wind or from the car's own weight on a high-crowned road. The car will start to move laterally. The ratio of its lateral velocity to the forward velocity produces that slip angle required to generate the tire side forces needed to balance the external side force. Thus, smaller levels of cornering stiffness will result in larger amounts of lateral drifting for a given constant, lateral disturbing force, and vice versa. Similarly, as forward speed is increased, larger lateral velocities will result from a given level of side force in order to produce the required slip angles to establish the necessary force equilibrium. Thus pneumatic tires have the property of providing less lateral stiffness with respect to space, as forward velocities are increased. The consequences of this characteristic of tires are indeed significant. We see that at forward velocities approaching zero, the tire acts as a wheel guided on a rail (i.e., infinite lateral stiffness), while at speeds approaching infinity, the tire appears to have zero lateral stiffness, hence, the "sure-footed" or "skittery" feel.

Not only do tires provide the lateral-guiding stiffness of the vehicle, there is also the distribution of the stiffness of the individual tires with respect to the location of the center of gravity of the vehicle. Thus, when the vehicle is given a component of lateral velocity (due to an applied side force) moments may arise that tend to line the vehicle up with its total velocity vector (i.e., reduce the lateral velocity to zero) or to increase the angle between the center line of the vehicle and its total velocity vector (i.e., increase the lateral velocity beyond the initially imposed values). In the former case, the vehicle is said to be directionally stable (in a static sense) and in the latter case to be directionally unstable.

Tires Influence Turning

These two characteristics of pneumatic-tired vehicles, namely, the total, lateral guiding stiffness and the directional stability, influence both the steady-state turning radius and the transient (i.e., time varying) turning behavior. For example, the directional stability, i.e., the aligning-moment characteristic discussed above, causes the turning radius per unit value of front-wheel angle or steering-wheel angle to vary with speed. Figure 3 shows that the path curvature (i.e., the inverse of the turning radius), per unit value of steer angle, decreases with increasing speed if the directional stability or static margin* is positive. The path curvature per unit steer angle remains constant, irrespective of speed, for a zero static margin and it increases with speed if the static margin is negative. Note, however, that this influence of directional stability on the path curvature established in a steady turn is small or negligible at low speeds but is extremely influential at high speeds. The practical consequences of this phenomenon can be observed by changing speed on a constant radius curve and noting the steering correction that must be made to hold the vehicle on its curved path without changing the radius of the turn. The vehicles that we drive are normally directionally stable and thus we would note that if we speed up on a constant radius curve we would have to increase our steering-wheel displacement. If we slowed down, on the other hand, we would have to back off on our steer angle in order to keep the vehicle from running off the inside of the curve.

Figure 4 shows the effect of speed and static margin on the transient or dynamic response of the automobile

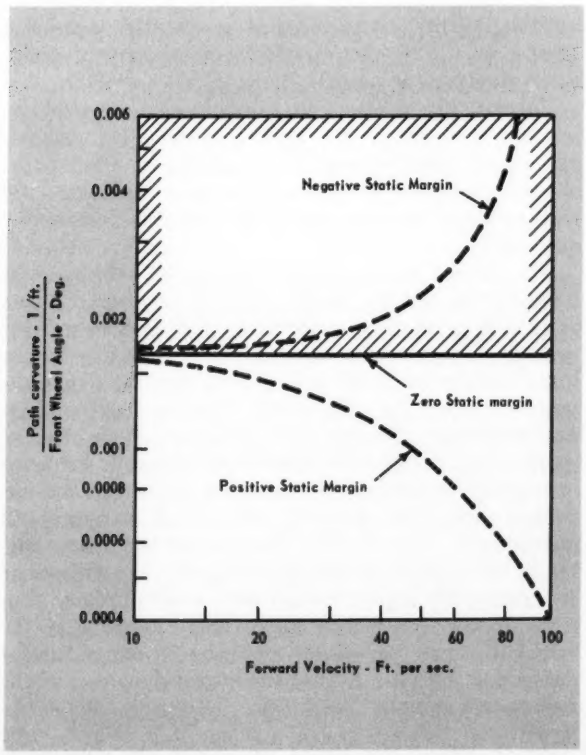


FIG. 3 — **Influence of static margin on the steady-state curvature response.**

*A positive static margin corresponds to static, directional stability, a zero static margin to neutral, or zero, directional stability, and a negative static margin to static, directional instability.

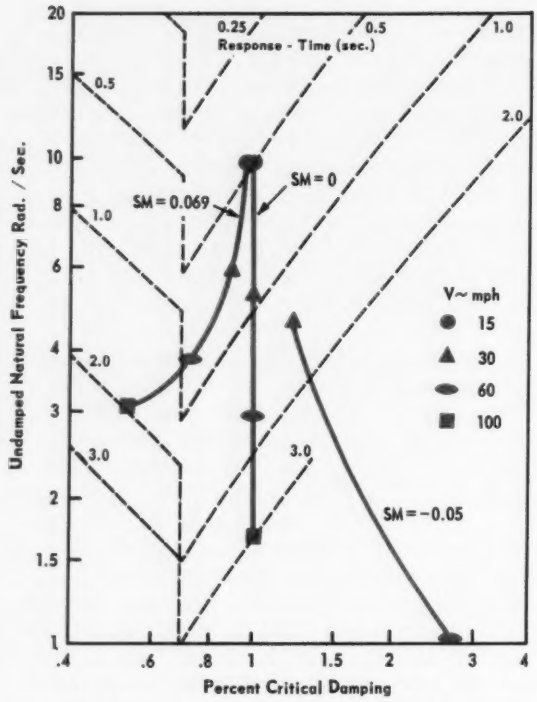


FIG. 4 — **The influence of speed and static margin on the directional dynamics of a four-wheeled pneumatic-tired vehicle.**

to a steering input. Lines of constant response time* are shown superimposed on the figure as a function of the dynamic indices, undamped natural frequency (see ordinate) and per cent critical damping (see abscissa). We see that the vehicle with neutral directional stability (SM = 0) undergoes no change in the damping index as speed is increased. The observed change in response time of 0.5 second at 15 mph to 3.0 seconds at 100 mph is a direct result of the effective decrease in lateral stiffness provided by the pneumatic tires. Similar increases in response time are noted for the directionally-stable vehicle and the directionally-unstable vehicle, as speed is increased; however, the character of the transient motions produced by a steering input is different for the two cases. The decrease in damping ratio of the directionally-stable vehicle, as indicated on Figure 4, shows that the dynamic or transient motions become more oscillatory in character as speed is increased. Conversely, the directionally-unstable vehicle does not exhibit this oscillatory behavior, but rather, a speed is eventually reached at which the vehicle continues to turn in an increasingly tighter circle once a given steer angle is established. If one were to drive a directionally-unstable vehicle at, or above, this critical speed he would note that he would have to continually make steering corrections to keep the vehicle on a straight path. If he did not make these continual corrections, the car would proceed to turn in an ever decreasing radius until a skid would be produced.

It should be pointed out that the above conclusions hold only for what may be termed the "linear" automobile, i.e., an automobile that can be described by a linear, mathematical model. When a vehicle is driven under conditions wherein the side forces on the tires become large relative to the weight of the vehicle, a linear model no longer applies. It then becomes necessary to consider the actual side-force slip-angle relationship of tires, as it occurs in practice, in order to analyze the skid behavior of an automobile. Tire data can be obtained for this purpose with test equipment such as that described in Vol. 4, No. 2 of Research Trends Summer 1956. This equipment permits measurement of forces and moments which act on a moving tire.

*Response time is defined here as the time required to reach and remain within 95 percent of the steady-state response to a step input.

Other Forces Acting on Tire

Non-linear phenomena need to be included in equations of motion if they are to be valid at conditions wherein large slip angles exist and large tractive efforts are applied for propulsion. The influence of change in vertical load on each tire, due to roll effect (a redistribution of loads caused by the finite height of the center of gravity above ground), and the influence of longitudinal thrust need to be accounted for in determining the side force output of a given tire. In addition, non-linear properties of the suspension that have a bearing on the relationship between rolling moment and the roll displacement/velocity need to be included in the mathematical representation of the vehicle. Studies of the steady-state turning behavior of automobiles at large lateral accelerations have been conduced for General Motors and a more extensive study of the turning and drawbar pull performance of wheeled and tracklaying vehicles has been conducted for the Ordnance Tank-Automotive Command of the U.S. Army.[1] All of this more recent work has been only analysis and experiments remain to be performed to (1) verify the theory and (2) obtain knowledge of handling-quality characteristics of vehicles operating at or near the maximum side-force capacity of pneumatic tires (i.e., at or near the skid).

To place the automobile handling-qualities problem in some perspective you may wonder: "Do present-day automobiles possess the attributes of good path-changing qualities, good course-keeping qualities, good road-holding qualities, and good emergency-handling qualities?"

The answer is that a pneumatic-tired vehicle, with its center of gravity about midway between the two axles with present-day suspensions and modern steering systems, does possess all these attributes to a degree, but some vehicles are better than others. But the significant point is that the automobile has evolved without possessing any ***fundamental deficiencies*** in steering stability and control. A study of its dynamic behavior in response to steering, nevertheless points up the important influence of speed and static margin, both individually and together. We see that provisions currently being made to permit the automobile to operate at increasingly higher speeds, such as the present program to provide better roads, will require that the vehicle designer pay closer attention to the particular design details that influence the lateral dynamics of the automotive vehicle.

[1]Clark, D., Segel, L. The Steering and Drawbar-Pull Performance of Pneumatic-Tired Vehicles — paper presented at First International Conference on Soil-Vehicle Systems, Turin, Italy, June 5-9, 1961.

Moon Bounce . . .

and

SIGNALS FROM SPACE

by H. ANDREAS VON BIEL

At CAL's Radio Physics Laboratory there are three research programs underway: high power radar research (discussed in the Fall, 1960, Research Trends Vol. VIII, No. 3), radio wave propagation, and radio astronomy. A site at Newstead, N. Y. 20 miles northeast of Buffalo, and 12 miles from the Laboratory, was selected because the antennas used for these programs could be located on a bluff with an excellent unobstructed view of the northern horizon.

One of the best and least expensive ways to study the space environment, is to transmit radio signals through it. If the nature of the signals is known, then the modifications introduced by transmission through the medium under investigation will yield useful information.

A short distance from the big 60-foot parabolic antenna used for high power radar research stands a smaller antenna. We are misled by the comparative size of the small antenna, for it is a rather substantial radio telescope with a reflector diameter of 28 feet. This instrument, installed on an equatorial mount, is designed so that the axis of rotation is parallel to the earth's axis of rotation. That is, it points approximately toward the north star. Accordingly, the antenna is capable of continuously tracking any celestial body as it moves across the sky.

Program Has Three Aims

The radio wave propagation research program for which the 28-foot antenna is used has three aims: the detection of radio signals reflected from the moon, the detection of radio echoes from the aurora borealis (or northern lights), and the study of radio noise power received from radio stars — sources outside our own solar system.

For all parts of this program, sponsored by the Cambridge Research Laboratories of the Office of Aerospace Research of the U.S. Air Force, the 28-foot antenna is used for receiving purposes only. It can be thought of as the receiving portion of a bistatic radar, the transmitter for which is located at the Cambridge Research Laboratories in Bedford, Massachusetts, a distance of 375 miles.

The 28-foot dish was first used for a tropospheric communication (scattering) experiment, at a frequency of 915 megacycles. It was formerly thought that communication at such frequencies was limited by line-of-sight; that is, that one could not regularly use these radio signals for communication over the horizon. The need for more and more communication channels to relieve the over-taxed lower frequency channels was the motivation for research to see if higher frequencies might be used.

FIG. 1 — **28-foot radio telescope.**

By using a sensitive receiver, CAL was regularly able to receive signals from the 10 kilowatt transmitter at Bedford. Those signals had been scattered by atmospheric irregularities about 25,000 feet above Utica, New York, halfway between Bedford and Buffalo. Had our receiver been high enough to "see" Bedford directly, the signal would have been about two billion times stronger.

The success of that program led to the idea that the transmitter and an improved receiver could be used for more difficult studies. One example would be to transmit known signals to the moon and note modifications produced by the moon, the two-way trip through the upper atmosphere, and the 240,000 miles of intervening space. Similar experiments are also conducted by reflecting the signal from the electrically charged particles in the aurora.

Parametric Amplifier Used

Of course the intensity of the radio echoes detected at the antenna is extremely small. In the case of the moon echoes, 10,000 watts are generated by the transmitter. This power is focused into a beam which effectively increases the beam power 4000 times. A similar focusing and concentration of power occurs at the receiver, and yet a power of only 10^{-16} watts is received. This extremely weak signal is first amplified by a parametric amplifier placed near the focus of the antenna, and further amplification occurs in the receiver (inside the radio physics building) to such an extent that usable recordings can be made. The sensitivity of the receiver is such that the lunar echo power is more than 1000 times greater than the minimum detectable signal!

FIG. 2 — **Rotating horn feed and parametric amplifier.**

FIG. 3 — **915 megacycle receiver and recording equipment.**

FIG. 4 — **Control panel for 28 foot radio telescope.**

The degree of excellence of sensitive receivers is described by what is called the noise figure or the excess noise temperature. In any receiver, if the amplification is increased more and more, eventually a point is reached at which "noise" — something equivalent to a hiss in a home radio — becomes so loud that it masks a faint signal. Because of the atomic and electronic nature of matter, it is theoretically and practically impossible to completely eliminate this noise.

Receiver Has Low "Noise" Figure

For an ideal receiver, the noise figure would be 1.0; and the excess noise temperature is 0° Kelvin or — 460°F: at the L-band frequency used here a noise figure of 4.0 (corresponding to an excess noise temperature of 895°K) would be considered good practice. The receiver designed and built at CAL has a figure of 1.2, i.e., an excess noise temperature of 96°K. Its sensitivity can be demonstrated by sequentially connecting a resistor at room temperature and one immersed in liquid nitrogen to the input of the amplifier and by measuring the difference in noise power generated by the resistors at room temperature and at a temperature more than 300°F below zero.

An interesting consequence of such unusual sensitivity is that it is useful only when the antenna is pointed at the sky. When the antenna is depressed to an angle near the horizon, the radiation from the earth, which of necessity is at normal temperatures, brings the noise up, and hence the unusual sensitivity is wasted. Actually, even more sensitive receivers have been built, but there are formidable problems in mounting them in front of a big dish so that they are struck by an equivalently small amount of radiation from the earth or surrounding objects at ambient temperatures.

The objective of the lunar echo program is to determine the radio frequency characteristics of the lunar surface. In an optical telescope the moon looks very mountainous especially at the terminator* where the sun's rays strike the moon at a grazing angle. In fact, the mountainous-looking regions have contours more like rolling hills. Because of irregularities in our own atmosphere we cannot resolve any object on the moon smaller than several hundred feet in size. Nevertheless, (because the full moon is proportionately much brighter than the quarter moon) we know the surface is not smooth. Using radio frequencies (L-band has a wavelength of about a foot), some interesting observations can be made. Most of the return comes from about one-seventh of the surface. These measurements do not say whether the roughness is like sand, or stones, or boulders.

If the moon were perfectly smooth, the received signal would be a replica of the signal transmitted to the moon from Bedford. If the surface were rough, some of the signal would be reflected from boulder to boulder, destroying its coherence. This latter is clearly the fact because about 47 per cent of the total power returned from the moon has completely random characteristics.

Random return from the moon stems from such other factors as the earth's ionosphere, and lunar rotation and apparent oscillation (the moon rotates once in about four weeks, but its orbit about the earth is elliptical, not circular, so that the surface of the moon is not at rest as we see it).

Aurora Affects Radio Waves

In broad terms, the purpose of the auroral echo program is to determine the nature of the auroral disturbances, and to study their effects on radio wave propagation. The exact mechanisms giving rise to the spectacular displays of aurora borealis are not known, but they are closely connected with huge explosions on the sun. During these solar explosions vast amounts of material are emitted, which, in cloud-like fashion, drift away from the sun. The charged particles (such as electrons and ions) in these clouds, after their transit from the sun to the earth, are captured by the earth's magnetic field, where they spiral around the magnetic

*The line dividing the illuminated and the unilluminated part of the moon's or a planet's disk.

lines of force in long narrow tubes. Frequently, the energy in these particles is sufficiently large to cause a glow.

Even more frequently, however, no auroral display is seen, but the radio propagation effects are nevertheless very noticeable and are often characterized by complete disruption of radio communication channels, sporadic fading of radio signals, and sometimes of abnormal radio wave propagation between two points. For example, when the Bedford transmitter beams its signal into the northern sky, under normal circumstances no echo is returned to the Newstead antenna. During auroral disturbances, however, echoes of the Bedford transmission are received sporadically. The intensity of these echoes is unpredictable. On occasions their signal strength is ten times larger than the lunar echo, and just as frequently it is hardly detectable. As in the case of the lunar echo, auroral radio echoes show little resemblance to the original signal characteristics. The nature of the variation between transmitted and received signals yields information on the electrical nature of the aurora.

A third part of the program is the study of the earth's ionosphere by the use of radio sources outside the solar system, or in fact outside our own galaxy of a hundred billion stars, of which our own sun is a comparatively unimpressive example. Seen beyond the constellation of Cygnus (prominent in the summer) the brightest star of which is "only" 1000 light years* distant, the 200-inch Mt. Palomar telescope barely shows two galaxies in collision, (or at least in close proximity) at a distance of about 550 million light-years. This cosmic cataclysm known as Cygnus A might be expected to emit radiation — a fantastic amount in fact.

*A light year is the distance covered by an object if this object were to travel for one year at a speed of 186,000 miles per second.

Signals from Cygnus A Received

At Newstead we are now receiving the radio emissions that left Cygnus A 550 million years ago. The enormous free space attenuation of the signal at this tremendous distance (526 decibels) is so great that the intensity at Newstead is only about one thousandth as great as the equivalent noise of our very low noise receiver. However, since our receiver is unusually stable (a variation in gain of 0.1% per 3 hours), we are able to detect this radiation by comparison of lengthy looks at Cygnus A and adjacent empty sky.

A source in the constellation of Cassiopeia* which is "only" 10,000 light years away in our own galaxy emits a billion times less power, but it is much nearer, and comes in stronger. Since Cassiopeia has a far northern declination, it never sets, and makes a convenient source for ionospheric studies.

In the case of these sources we observe the signal after it passes through our own ionosphere, so that the signal amplitude fluctuations must be ascribed to the ionosphere. These fluctuations lead subsequently to information about the irregularities of electron concentration there.

With modern techniques, the possibilities of receiving signals from a few hundred miles away by tropospheric scatter, from the upper atmosphere (aurora), from the moon, from our galaxy, and some other galaxies, offer interesting areas of research for the radio physicist.

*Remnants of a supernova that was seen exploding 260 years ago.

ABOUT THE AUTHORS

LEONARD SEGEL, **author of "The Automobile and Its Driver," has been a member of the Laboratory's technical team almost since its origin and is assistant head of its Vehicle Dynamics Department.**

A graduate of the University of Cincinnati in aeronautical engineering, Mr. Segel also holds a master's degree in mechanical engineering from the University of Buffalo.

His experience in aircraft stability and control problems provided an excellent background for applying aeronautical research to the dynamics of automobile stability and control.

In addition to research in flight data measurement systems, and in methods for predicting the flow alignment ahead of an aircraft, Mr. Segel has directed considerable effort toward analysis of full-scale response data and toward developing analytical techniques. Land locomotion mechanics, tire mechanics and submarine maneuvering control are other areas in which he has concentrated.

In 1958 Mr. Segel was awarded the Crompton Lanchester Medal by the Institution of Mechanical Engineers of the United Kingdom for his work in the field of automobile dynamics.

He is a former naval officer and a member of Sigma Xi.

H. ANDREAS von BIEL, **author of "Moon Bounce and Signals from Space" is an Associate Electrical Engineer in the Laboratory's Radio Physics Section of the Applied Physics Department. He is project engineer for the investigation of the lunar surface and properties of the auroral ionosphere by radio propagation.**

Born in the United States of German parents, Mr. von Biel received much of his elementary and secondary education in Germany. Upon returning to America following World War II, he entered Cornell University from which he holds Bachelor's and Master's degrees in electrical engineering. While completing requirements at Cornell for the advance degree, Mr. von Biel served as teaching assistant there.

Before joining the Laboratory in 1959, he was on active duty with the U.S. Navy as electrical and C.I.C. officer.

Mr. von Biel's professional specialties are radiowave propagation antennas and communications. He is a member of Sigma Xi.

RECENT CAL PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited, and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"THE FINITE ASPECT RATIO JET FLAP," Hartunian, Richard A.; CAL Report No. AI-1190-A-3; October 1959; 75 pages.*

The lifting surface equations for the finite aspect ratio jet-flapped wing are developed, assuming small perturbations of the undisturbed flow. The lifting surface, in this case, is comprised of the wing and the curved portion of the jet sheet. The governing integro-differential equations are written in a form analogous to ordinary finite aspect ratio wing theory, which suggests procedures of approximation in terms of the aspect ratio of the lifting surface. The limiting case of large aspect ratio is given detailed consideration.

"IMPROVEMENT OF CR-NI-MO BASE ALLOYS BY VACUUM MELTING AND CASTING," Gillig, Franklin J.; CAL Report No. KA-1289-M-6; September 1959; 13 pages.

The objective of this program was to investigate the effects of minor changes in composition and vacuum melting on the high temperature mechanical properties of iron base alloys containing 20 Cr-20 Ni-5 Mo and various minor additions of Cb, W, Ti, B and Al. Twenty-one heats were cast with varying compositions. The 100-hour rupture strength at 1500°F. was used as the basis for rating the elevated temperature strength.

"HIGH-POWER MICROWAVE TUBE STUDY," Breeden, F. C., Groth, Lloyd, H.; CAL Report No. UC-1415-P-1; August 1960; 149 pages.

A study is made of microwave tubes that are applicable to the generation of continuous-wave energy at the 100 kw level and at frequencies between 2 and 10 Gc. A tube is required for use in a passive-satellite communication system — characteristics for which are not specified at this time. The tube must be capable of changing frequency at a rapid rate over a maximum excursion of 500 Mc.

"STUDY OF CONTROL SYSTEMS FOR ARTILLERY ROCKET DISPERSION REDUCTION DURING BOOST," Rice, Roy S., Crimi, Peter; CAL Report No. GM-1265-S-2; July 1960; 113 pages.

This report describes the second year's activity of a two-year program on the study of deflection dispersions occurring during boost of fin-stabilized artillery rockets. Particular emphasis has been directed toward the use of internal control systems, containing combinations of gyroscopes and accelerometers, to reduce the magnitude of these dispersions by an order of magnitude below those of a non-controlled rocket.

"BOUNDARY-LAYER TRANSITION AND HEAT TRANSFER IN SHOCK TUBES," Hartunian, Richard A., Russo, Anthony L., Marrone, Paul V.; CAL Report No. AD-1118-A-3; December 1959; 20 pages.

An experimental study is made of the wall boundary layer in a shock tube operated over a wide range of shock Mach numbers and pressure levels in air, including those for which real gas effects exist. Transition distances are determined, and correlated in terms of the transition Reynolds number based on a characteristic length for this boundary layer. Data from independent shock tube studies are also included in this correlation.

"ANALOG NETWORK TO CONVERT SURFACE TEMPERATURE TO HEAT FLUX," Skinner, George T.; CAL Report 100; February 1960; 37 pages.

The work reported in this paper indicates that there is little difficulty in obtaining practical networks for converting the output of a thin-film gauge to an electrical signal proportional to surface heat flux. The type of network that has been described gives every indication of leading to satisfactory results if it is properly adjusted to the type of use for which it is intended.

"THEORY OF SPREAD F BASED ON ASPECT-SENSITIVE BACK-SCATTERED ECHOES," Renau, Jacques; Reprinted from the Journal of Geophysical Research, Vol. 65, No. 8; August 1960; 9 pages.

To explain spread echoes from the F region the concept of aspect sensitivity was incorporated in our derivations of h'f curves using the assumption that the magnetoionic components can be treated separately. The shape of the h'f curves, as well as the extent of range and frequency spreading, was deduced for ionospheric stations located at various magnetic latitudes.

"A STUDY OF THE ACCURATE RE-ENTRY AND PRECISION LANDING OF AN ORBITAL EARTH SATELLITE, PART II," Dell'Amico, Fred, DeLeys, Norman J.; CAL Report No. VF-1351-H-2; June 1960; 102 pages.

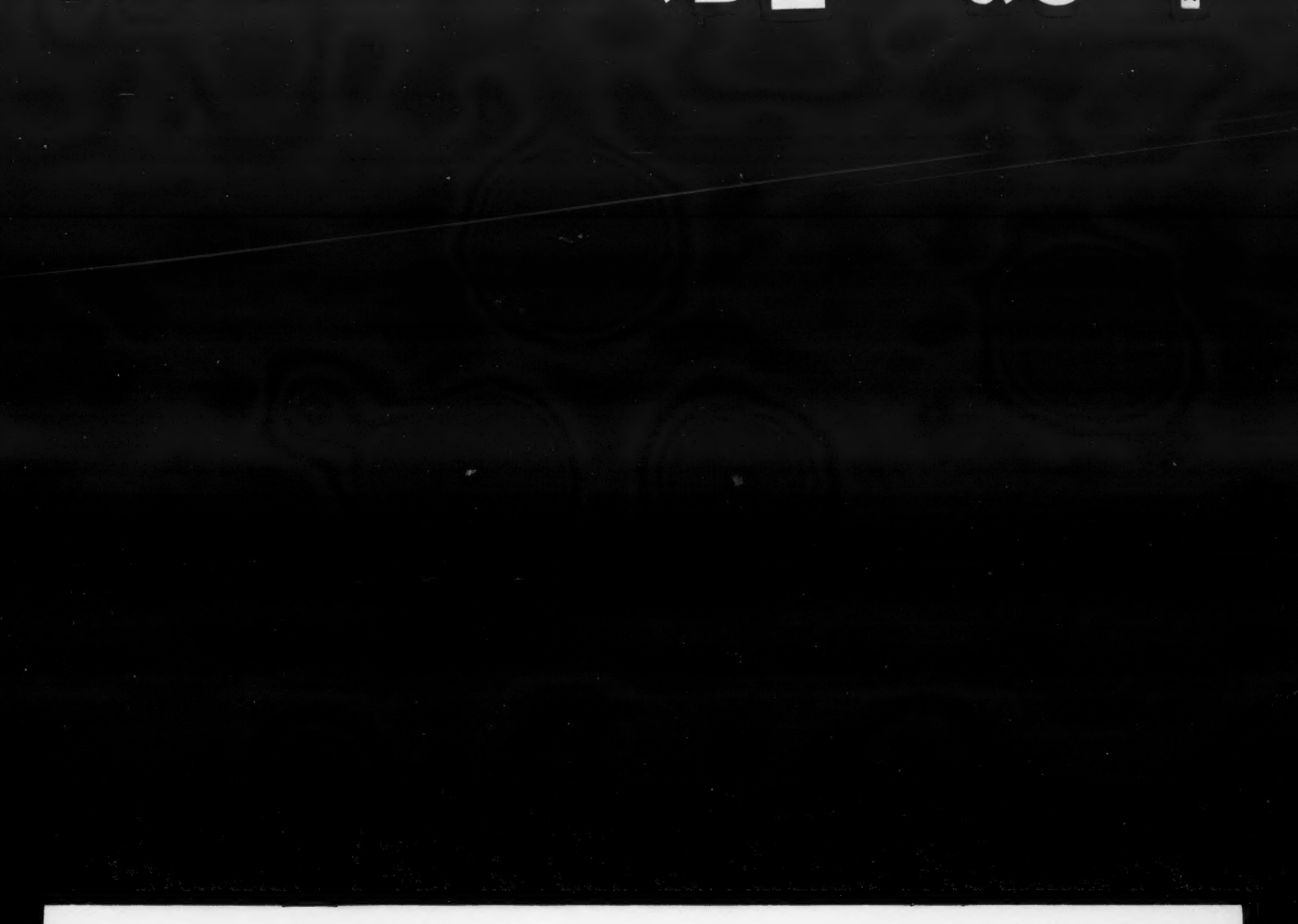
Accurate re-entry and precision landing of earth satellites is investigated. Major emphasis is placed on gross vehicle configuration, re-entry trajectories, dispersions at ejection from orbit and command guidance using a two-station ground radar system. A conclusion that command-guided re-entry is feasible is reached.

"FUNDAMENTALS OF INERTIAL SYSTEMS," Dell'Amico, Fred, Rice, Roy S.; CAL Report 107; June 1959; 49 pages.

Progress in inertial navigation during the past decade is a result of increased emphasis on techniques for military purposes and rapid advances made in the technology of inertial instruments. The subject of inertial navigation is discussed in outline form, with emphasis on theory and performance rather than on design and construction.

"THE AERODYNAMIC APPRAISAL OF STOL/VTOL CONFIGURATIONS," Vidal, Robert J., Sowyrda, Alexander, Hartunian, Richard A.; I.A.S. Paper No. 60-37; June 1960; 78 pages.

Methods for estimating the characteristics of different STOL/VTOL configurations are discussed, with special emphasis given to the effect of interactions between the lifting system and the propulsion wake. The results of a small perturbation theory for the finite high aspect-ratio jet flap are presented. The results of the theory are found to be in good agreement with experiment over a wide range of aspect ratios, angles of attack, jet deflections, and jet momentum coefficients.

"THE EFFECTS OF POROUS WALLS ON THE POWER OUTPUT OF LIQUID FLUIDIZED BED REACTORS," Silverstein, Calvin C.; CAL Report No. 102; March 1960; 33 pages.

The use of porous walls to increase the power density of liquid-fluidized-bed reactors is suggested. The improvement in power density is shown in dimensionless form as a function of the entrant flow velocity and temperature rise of the fluidizing liquid. Experiments are described in which the entrant velocity in porous-wall beds was compared with that in a solid-wall bed.